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RESEARCH MEMORANDUM

6 PREDICTION OF CRATER DIMENSIONS FOR THE TEAPOT UNDERGROUND TEST

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14 Rept. no. RM-1449

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ABSTRACT

Crater dimensions which may be anticipated for the underground explosion of a 1.2-KT nuclear device as part of the TEAPOT nuclear test series are discussed. Estimates are made on the basis of available crater measurements at the Nevada Test Site and appropriate scaling procedures. A value approximately half way between estimated upper and lower limits of 210 and 167 feet for the crater radius, or about 190 feet, is given. Other characteristic dimensions are estimated such as the diameter at the top of the lip, the height of the lip above the original surface, and the depths measured from the top of the lip or from the original surface.

INTRODUCTION

As a part of the "TEAPOT" nuclear test series, an underground explosion of a 1.2 KT nuclear device at a scaled depth of 0.5 ft/lb$^{\frac{1}{3}}$ (actual depth - 67 ft.) is planned. Consequently, it is of interest to estimate the crater dimensions which may be anticipated on the basis of available crater measurements at the Nevada Test Site and appropriate scaling procedures.

COMPARISON OF TNT AND NUCLEAR TEST CRATERS OBSERVED AT THE NEVADA TEST SITE

Table I summarizes the data on the apparent crater radii for both high explosive and nuclear craters observed at the Nevada Test Site.(1)(2)(3) The corresponding scaled radii and scaled charge depths are also given.

The average scaled radius ($\lambda = R^1/W^{\frac{1}{3}}$) for each scaled charge depth (λ_c = charge depth/$W^{\frac{1}{3}}$) is plotted as a circle in Figure 1. Where several values of λ were available for a given value of λ_c, the range of variation is indicated by vertical bars. Also shown for comparison are Lampson's(4) curve for TNT craters in sand and the Isthmian Canal Studies(5) curve for TNT exploded in sandstone.

It will be noticed that the two latter curves have their maximum values of λ for a value of λ_c near unity and that the Nevada TNT data are consistant with a maximum at $\lambda_c = 1$.

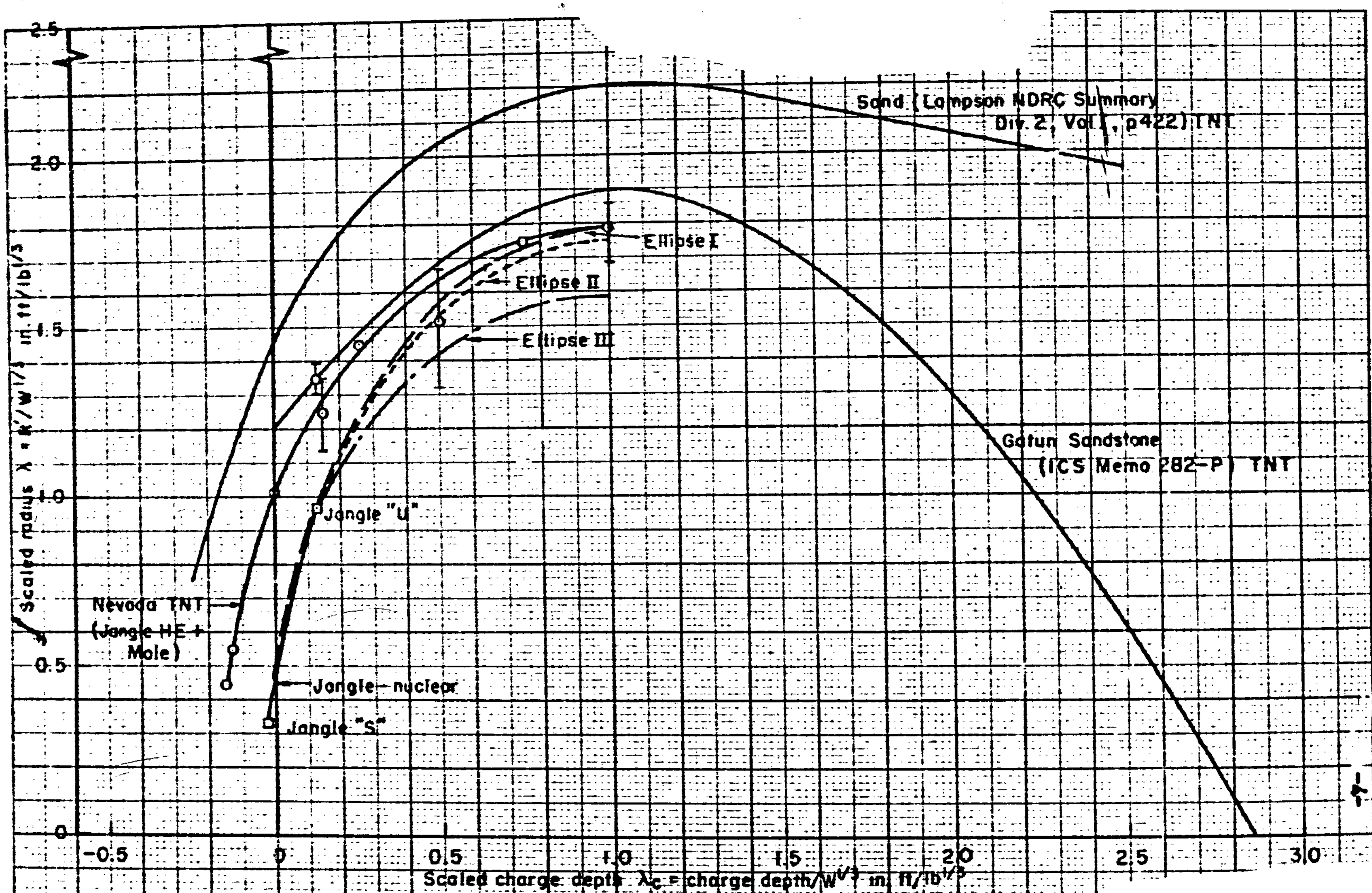

Fig. 1 — Summary of AEC-Nevada test site crater tests
(scaled radii of apparent craters measured at original ground level)

RM1449-1

TABLE I

SUMMARY OF DATA ON APPARENT CRATER RADII AT THE ORIGINAL GROUND SURFACE FOR THE AEC NEVADA TEST SITE

Identification of Round	Weight of Charge W(lbs.)	$W^{1/3}$ (lbs.)$^{1/3}$	Crater Radius R' (feet)	Scaled Charge Depth λ_c (ft/lbs.$^{1/3}$)	Scaled Radius λ (ft/lbs.$^{1/3}$)
Jangle HE-4 (TNT)	2560	13.68	6.1	-0.15	0.45
Mole 207 (")	256	6.35	3.5	-0.13	0.55
" 206 (")	256	6.35	6.4	0.00	1.01
" 205 (")	256	6.35	8.8	0.13	1.39 av.
" 403 (")	256	6.35	8.33	0.13	1.31 1.35
Jangle HE-1 (")	2560	13.68	18.5	0.15	1.35 av.
" HE-2 (")	40000	34.20	39.0	0.15	1.14 1.25
Mole 204 (")	256	6.35	9.2	0.26	1.45
" 405 (")	256	6.35	9.18	0.26	1.45
" 203 (")	256	6.35	8.4	0.50	1.32
" 406 (")	256	6.35	10.0	0.50	1.58 av.
" 401 (")	256	6.35	10.58	0.50	1.67 1.52
Jangle HE-3 (")	2560	13.68	20.5	0.50	1.50
Mole 402 (")	256	6.35	11.08	0.75	1.75
" 202 (")	256	6.35	11.5	1.00	1.81
" 212 (")	256	6.35	10.7	1.00	1.69 av.
" 404 (")	256	6.35	11.78	1.00	1.86 1.79
Jangle "S" (Nuclear)	2.4×10^6	134	45	-0.0261	0.336
" "U" (")	2.4×10^6	134	129	0.127	0.963

An attempt was made to fit a parabola of the form

$$(\lambda_c - \lambda_{co})^2 = -4p(\lambda - \lambda_o) \qquad (1)$$

to the Nevada TNT data, but it was found that no set of values for the parameters λ_{co}, λ_o and p gave a good fit to the data over the whole range of λ_c. However, a good fit to the Nevada TNT data was obtained with an ellipse of the form

$$\frac{(\lambda_c - \lambda_{co})^2}{a^2} + \frac{(\lambda - \lambda_c)^2}{b^2} = 1 \qquad (2)$$

with the following values of the parameters λ_{co}, λ_o, a and b:

$$\lambda_{co} = 1$$
$$\lambda_o = 0.2597$$
$$a = 1.1590$$
$$b = 1.5303$$

This ellipse is the solid curve drawn through the Nevada TNT data in Figure 1. The constants were chosen so that the curve passes through the three points (-0.15, 0.45) (0.15, 1.3) and (1, 1.79) and has a maximum at $\lambda_c = 1$.

The Jangle "S" and "U" data are indicated as squares, in Figure 1, for comparison with the Nevada TNT data. It is seen that the "scaled radius" of the apparent crater at the original surface, for Jangle "S", is 0.36 of that for the Nevada TNT curve, at the same scaled charge depth. For the Jangle "U" crater this ratio is 0.76. The increase of the cratering efficiency of the nuclear explosions relative to TNT, as the "scaled charge depth" is increased,

makes the prediction of the TEAPOT "ESS" crater dimensions dependent on some kind of extrapolation, of a curve connecting the Jangle "S" and "U" points, to a value of $\lambda_c = 0.5$ ft/lb$^{1/3}$. The good fit of an ellipse to the Nevada Proving Ground TNT data suggests that an ellipse might also be used to extrapolate the nuclear λ vs. λ_c curve. However, the fact that only two measured points on the nuclear crater curve are available, means that there are not sufficient points to determine a unique ellipse through the Jangle "S" and "U" points; i.e., there are not enough measurements to determine the four parameters in Equation (2) above. The similarity between the Isthmian Canal Studies TNT curve for Gatun Sandstone, the Nevada TNT and Lampson's curve for Sand suggests that the nuclear curve for Nevada soil conditions may also have its maximum near $\lambda_c = 1$. Even if it is assumed that $\lambda_{co} = 1$, an additional assumption is necessary to determine a unique ellipse of the form of Equation (2) through the Jangle "S" and "U" points.

The fact that the initial temperatures and pressures in nuclear explosions are much higher than for chemical explosions suggests that the nuclear explosion would never reach as high a cratering efficiency as TNT, even at the optimum charge depth. For example, in air, the fraction of the energy released in a nuclear explosion which appears as mechanical blast energy is never as large as for TNT explosions because a much larger fraction of the energy is radiated away as heat and light and also the air is left at a higher temperature behind the shock front because of the higher temperatures and pressures in the shock front.

Consequently, it appears likely that the maximum value of λ for the Nevada TNT curve, i.e., $\lambda = 1.79$ ft/lb$^{1/3}$, should represent an upper limit to the Nevada nuclear scaled crater radius for λ_c near unity.

If an ellipse of the form of Equation (2) is made to pass through the Jangle "S" and "U" points and have a maximum at $\lambda = 1.79$ ft/lb$^{\frac{1}{3}}$ and $\lambda_c = 1$, then the constants in Equation (2) for the Nevada nuclear scaled radius curve are:

$$\lambda_{co} = 1$$

$$\lambda_o = -0.08168$$

$$a = 1.0521$$

$$b = 1.8717$$

The curve, drawn through the Jangle "S" and "U" points and labeled No. 1 in Figure 1, is a graph of the above ellipse and yields a value of $\lambda = 1.56_5$ ft/lb$^{\frac{1}{3}}$ for $\lambda_c = 0.5$. This is equivalent to an apparent crater radius, at the original ground level, of about 210 feet as an upper limit for a 1.2 KT nuclear explosion, burst at a depth of 67 feet.

Since the nuclear scaled radius is 0.76 of the scaled TNT radius at a scaled charge depth of 0.127 ft/lb$^{\frac{1}{3}}$, any guess for this ratio, at $\lambda_c = 1$, in the range from ~ 0.8 to 1.00 would appear to be reasonable. Two additional ellipses through the Jangle "S" and "U" points are shown in Figure 1, as numbers II and III, in order to examine the sensitivity of the TEAPOT "ESS" prediction to different but, perhaps, equally justifiable extrapolations of the Jangle crater data. The constants for these ellipses are:

Ellipse II	Ellipse III
$\lambda_{co} = 1$	$\lambda_{co} = 1$
$\lambda_o = 0$	$\lambda_o = 0.2597$
$a = 1.045_5$	$a = 1.028$
$b = 1.750$	$b = 1.332_5$

The corresponding maximum values of λ at $\lambda_c = 1$ are 1.75 and 1.59 $\text{ft/lb}^{1/3}$, and the ratios of these scaled radii to that from the Nevada TNT curve at $\lambda_c = 1$ are 0.98 and 0.89 respectively. The use of curves II and III to estimate the apparent radius for the TEAPOT "ESS" crater gives 206 and 191 feet, respectively, and together with the estimate of 210 feet from Ellipse I give an indication of the range of uncertainty which results from the unavoidable ambiguities in extrapolating the meager nuclear crater data.

It should be emphasized that many other factors also contribute to the uncertainty in such a prediction. Among these are the experimental uncertainties in both the nuclear and TNT curves due to the variations in crater dimensions, commonly encountered in repeated experiments under supposedly identical conditions; the assumption that the nuclear and TNT curves have their maxima at $\lambda_c = 1$; and the use of an ellipse to extrapolate the nuclear curve, simply because an ellipse is a good fit to the available Nevada TNT data. The lack of reproducibility of crater data is commonly as much as 20 or 30 percent. The contribution which the possible lack of validity of the various assumptions makes to the uncertainty in the predicted radius is difficult to assess, but it could be as large as that due to the experimental uncertainties.

Doll[6] has predicted an apparent radius for the TEAPOT "ESS" crater of 188 feet. Sachs and Swift[3] arrive at a slightly smaller value of 173 feet. The detailed procedures used by these workers to make their estimates are not available, but Ref. 3 indicates that Doll used all the available cratering data and assumptions concerning the "mechanical efficiency" to be assigned to the TEAPOT "ESS" device. The lower value predicted by Sachs and Swift is based on the observation that in some series of TNT tests, in which the charge

weight was varied over a large range but the "scaled charge depth" was held constant, the "scaled crater radii" decreased with increasing charge weight. This effect was attributed to a change in soil characteristics with increased depth of charge.

While some series of TNT craters, such as the UET rounds 312, 315 and 318[3] show this effect, other series such as the Mole rounds 203, 401 and 406 and Jangle HE-3 with a scaled depth of 0.5 $ft/lb^{1/3}$ do not (See Table I.) For the latter series the average scaled radius for the three Mole rounds (256 lbs. TNT) was 1.52 $ft/lb^{1/3}$, while the same quantity for Jangle HE-3 (2560 lbs. TNT) was 1.50 in good agreement with the smaller Mole craters.

Considering the small number of rounds in any one such series among the Nevada TNT tests and the rather large scatter normally encountered in cratering experiments, the effect can hardly be accepted as established. In fact, such considerations as these resulted in the decision to plot the average values of λ for each "scaled charge depth" to obtain the Nevada TNT curve shown in Figure 1.

Further, if the "scaled radius" taken from the ellipse fitted to the Nevada TNT data at $\lambda_c = 0.5$ is reduced by 0.76 (i.e., λ(Jangle "U")/ λ(TNT) = 0.76 for $\lambda_c = 0.127$) and scaled by the "cube root" law, a value of 167 feet would be predicted for the TEAPOT "ESS" radius. In other words, the assumption that the cratering efficiency of nuclear explosions relative to TNT does not increase for "scaled charge depths" greater than 0.127 $ft/lb^{1/3}$ gives a radius only slightly smaller than that predicted by Sachs and Swift and would appear to be a lower limit.

A value half way between the upper and lower limits or 188 feet is the same as that given by Doll and agrees well with the value of 191 feet predicted by Ellipse III through the Jangle nuclear points. See Figure 1.

From a prediction for the diameter of the TEAPOT "ESS" apparent crater at the original ground surface D', it is possible to arrive at estimates for other characteristic dimensions such as the diameter at the top of the lip, D, the height of the lip above the original surface, h, and the depths measured from the top of the lip, d, or from the original surface, d'.

A value of D can be estimated from D' by noting that for both the Jangle "S" and "U" craters the ratio D/D' was very nearly 1.165, and by assuming that it will be similar for TEAPOT "ESS". Having D, the modified Baldwin empirical relations[(7)(8)] may be used to predict h and d and then $d' = d - h$. The modified Baldwin relations connecting h and D, and D and d are:

$$\log h = -2.125 + 1.542 \log D - 0.097(\log D)^2 \qquad (3)$$

and

$$\log D = 0.843 + 0.6917 \log d + 0.1083(\log d)^2 \qquad (4)$$

respectively.

The resulting estimates for all the crater dimensions are summarized in Table II.

TABLE II

SUMMARY OF VARIOUS PREDICTIONS OF THE TEAPOT "ESS" APPARENT CRATER DIMENSIONS. (1.2 KT EXPLODED AT A DEPTH OF 67 FEET AT THE AEC NEVADA PROVING GROUND.)

Method of Extrapolation	Diameter at Original Surface D'(feet)	Diameter at Top of Lip D(feet)	Height of Lip h(feet)	Depth from Top of Lip d(feet)	Depth from Original Surface d'(feet)
I Ellipse I (Figure 1)	420	490	21	106	85
II Ellipse II (Figure 1)	412	480	20.5	104.5	84
III Ellipse III (Figure 1)	382	445	19	98	79
IV Using Scaled Radius from TNT Curve x 0.76 for $\lambda_c = 0.5$	334	390	16	87	71

The dimensions obtained for the TEAPOT "ESS" apparent crater by extrapolating the Jangle data with Ellipse III in Figure 1 (Number III in Table II) are probably as good an estimate as can be made with available data, i.e., about half way in between fairly reasonable upper and lower limits.

When the results of the TEAPOT "ESS" test are known, it will be possible to choose a unique ellipse through the nuclear points, in Figure 1, if the assumption of a maximum λ at $\lambda_c = 1$ is retained, i.e., if λ_{co} is taken equal to unity in Equation (2). While there is no theoretical reason for choosing an ellipse to fit the data, it appears to be a good fit in the region

$-0.15 < \lambda < 1$ for the Nevada TNT data and provides a convenient means for interpolating between the experimental points on a graph such as Figure 1. Even a modest extrapolation of such a curve through the region between $\lambda_0 = 0.5$ to $\lambda_0 = 1$ would probably not result in large errors of prediction but examination of the Lampson curve for sand (Figure 1) should indicate caution in extrapolating beyond the maximum. Extrapolation to higher "scaled heights of burst" above the ground would be even more risky.

Also, the fact that four experimental points would suffice to uniquely determine an ellipse should not be used to argue against more nuclear cratering experiments. The rather large scatter in crater data indicates that additional data might well make considerable improvement in the best average curve.

In conclusion the authors wish to acknowledge the helpful discussions with H. L. Brode conserning the relative cratering efficiencies of nuclear and chemical explosives.

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Title: Prediction of Crater Dimensions for the Teapot Underground Test
Authors: Hill, J.E., Gilvarry, J.J.
Pagination: 12
Report Date: March 1955
Report Number: RM1449

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